FORM PTO-1390 (Modified) (REV 10-95) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE

TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371

ATTORNEY'S DOCKET NUMBER
9847-0035-6X PCT

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR
09 / 508684

28 MAR 2000 PCT/PTO

INTERNATIONAL APPLICATION NO.	INTERNATIONAL FILING DATE	PRIORITY DATE CLAIMED
PCT/SE98/01740	**29 SEPTEMBER 1998**	**30 SEPTEMBER 1997**

TITLE OF INVENTION
ROTATING ELECTRIC MACHINE

APPLICANT(S) FOR DO/EO/US
Erland SORENSEN, et al.

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. ☒ This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. ☐ This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. ☒ This is an express request to begin national examination procedures (35 U.S.C. 371(f)) at any time rather than delay examination until the expiration of the applicable time limit set in 35 U.S.C. 371(b) and PCT Articles 22 and 39(1).
4. ☒ A proper Demand for International Preliminary Examination was made by the 19th month from the earliest claimed priority date.
5. ☒ A copy of the International Application as filed (35 U.S.C. 371 (c) (2))
   - a. ☐ is transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☒ has been transmitted by the International Bureau.
   - c. ☐ is not required, as the application was filed in the United States Receiving Office (RO/US).
6. ☐ A translation of the International Application into English (35 U.S.C. 371(c)(2)).
7. ☒ A copy of the International Search Report (PCT/ISA/210).
8. ☒ Amendments to the claims of the International Application under PCT Article 19 (35 U.S.C. 371 (c)(3))
   - a. ☐ are transmitted herewith (required only if not transmitted by the International Bureau).
   - b. ☐ have been transmitted by the International Bureau.
   - c. ☐ have not been made; however, the time limit for making such amendments has NOT expired.
   - d. ☒ have not been made and will not be made.
9. ☐ A translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371(c)(3)).
10. ☐ An oath or declaration of the inventor(s) (35 U.S.C. 371 (c)(4)).
11. ☒ A copy of the International Preliminary Examination Report (PCT/IPEA/409).
12. ☐ A translation of the annexes to the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371 (c)(5)).

Items 13 to 18 below concern document(s) or information included:

13. ☒ An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
14. ☐ An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
15. ☒ A **FIRST** preliminary amendment.
    A **SECOND** or **SUBSEQUENT** preliminary amendment.
16. ☒ A substitute specification.
17. ☐ A change of power of attorney and/or address letter.
18. ☐ Certificate of Mailing by Express Mail
19. ☒ Other items or information:

Request for Consideration of Documents Cited in International Search Report
Notice of Priority
Marked-up Copy of Specification
Response to petition Under 37 CFR 1.182
Form PTO-1449

PCTUS1/REV03

416 Rec'd PCT/PTO 28 MAR 2000

U.S. APPLICATION NO. (IF KNOWN, SEE 37 CFR 09/508684	INTERNATIONAL APPLICATION NO. PCT/SE98/01740	ATTORNEY'S DOCKET NUMBER 9847-0035-6X PCT

20. The following fees are submitted:.

BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)) :

- ☐ Search Report has been prepared by the EPO or JPO **$840.00**
- ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) **$670.00**
- ☐ No international preliminary examination fee paid to USPTO (37 CFR 1.482) but international search fee paid to USPTO (37 CFR 1.445(a)(2)) **$760.00**
- ☒ Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2) paid to USPTO **$970.00**
- ☐ International preliminary examination fee paid to USPTO (37 CFR 1.482) and all claims satisfied provisions of PCT Article 33(2)-(4) **$96.00**

				CALCULATIONS	PTO USE ONLY
ENTER APPROPRIATE BASIC FEE AMOUNT =				**$970.00**	
Surcharge of **$130.00** for furnishing the oath or declaration later than ☐ 20 ☒ 30 months from the earliest claimed priority date (37 CFR 1.492 (e)).				**$130.00**	
CLAIMS	NUMBER FILED	NUMBER EXTRA	RATE		
Total claims	28 - 20 =	8	x $18.00	**$144.00**	
Independent claims	5 - 3 =	2	x $78.00	**$156.00**	
Multiple Dependent Claims **(check if applicable).**			☐	**$0.00**	
TOTAL OF ABOVE CALCULATIONS =				**$1,400.00**	
Reduction of 1/2 for filing by small entity, if applicable. Verified Small Entity Statement must also be filed (Note 37 CFR 1.9, 1.27, 1.28) **(check if applicable).**			☐	**$0.00**	
SUBTOTAL =				**$1,400.00**	
Processing fee of **$130.00** for furnishing the English translation later than ☐ 20 ☐ 30 months from the earliest claimed priority date (37 CFR 1.492 (f)). +				**$0.00**	
TOTAL NATIONAL FEE =				**$1,400.00**	
Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31) **(check if applicable).**			☐	**$0.00**	
TOTAL FEES ENCLOSED =				**$1,400.00**	
				Amount to be: refunded	$
				charged	$

☒ A check in the amount of **$1,400.00** to cover the above fees is enclosed.

☐ Please charge my Deposit Account No. in the amount of to cover the above fees. A duplicate copy of this sheet is enclosed.

☒ The Commissioner is hereby authorized to charge any fees which may be required, or credit any overpayment to Deposit Account No. **15-0030** A duplicate copy of this sheet is enclosed.

NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137(a) or (b)) must be filed and granted to restore the application to pending status.

SEND ALL CORRESPONDENCE TO:

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March 28, 2000
DATE

09/508684

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9847-035-6X PCT
ENKEL8294

IN THE UNITED STATES PATENT & TRADEMARK OFFICE

IN RE APPLICATION OF	:
ERLAND SORENSEN ET AL	: ATTN: APPLICATION DIVISION
SERIAL NO: NEW APPLICATION (Based on PCT NO:SE98/01740)	:
FILED: HEREWITH	:
FOR: ROTATING ELECTRIC MACHINE:	

PRELIMINARY AMENDMENT

ASSISTANT COMMISSIONER FOR PATENTS
WASHINGTON, D.C. 20231

SIR:

Prior to examination on the merits, please amend the above-identified patent application as follows:

IN THE CLAIMS

Please cancel without prejudice or disclaimer Claims 1-27.

Please add new Claims 28-55 as follows:

--28. A rotating electric machine having a rotating field circuit, and configured to be directly connected to a distribution or transmission network, comprising:

an electric winding having

an electric conductor,

semiconducting surrounding the insulating layer; and

a detecting circuit configured to detect an earth fault in the rotating field circuit.

29. A machine as claimed in claim 28, wherein:

a potential of the first semiconducting layer being substantially similar to a potential of the conductor.

30. A machine as claimed in claim 28, wherein:

the second semiconducting layer is arranged to form a substantially equipotential surface surrounding the conductor.

31. A machine as claimed in claim 30, wherein:

the second semiconducting layer is connected to a predetermined potential.

32. A machine as claimed in claim 31, wherein:

said predetermined potential is earth potential.

33. A machine as claimed in claim 28, wherein:

at least two adjacent layers of the machine winding have substantially a same coefficient of thermal expansion.

34. A machine as claimed in claim 28, wherein:

the conductor comprises a predetermined number of strands, at least some of said predetermined number of stands being in electrical contact with each other.

35. A machine as claimed in claim 28, wherein:

each of said first semiconducting layer, said solid insulating layer, and said second semiconducting layer is firmly joined to adjacent layers along substantially a whole contact surface.

36. A machine as claimed in claim 35, wherein:

said layers are arranged to adhere to each other even when the electric winding is bent.

37. A rotating electric machine having a rotating field circuit, and configured to be directly connected to a distribution or transmission network, comprising:

a winding formed of a cable, said cable having

a current carrying conductor having a plurality of strands,

an inner semiconducting layer arranged around the current carrying conductor,

an insulating layer of solid insulating material arranged around said inner semiconducting layer, and

an outer semiconducting layer arranged around the insulating layer; and

a detecting circuit configured to detect earth faults in the rotating field circuit.

38. A machine as claimed in claim 37, wherein:

said cable further comprises a sheath.

39. A machine as claimed in claim 37, further comprising:

an excitation system configured to supply a voltage to a field circuit and configured to rotate with the field circuit; and

an injection and measuring unit for said detecting circuit and being arranged in said excitation system.

40. A machine as claimed in claim 39, wherein:

the detecting circuit comprises

an injection circuit configured to apply an injection voltage on a measuring circuit that is closed through an impedance between field winding and earth,

a measuring unit configured to measure an error current resulting in said measuring circuit from the injection voltage,

a rectifier unit arranged to form rectified absolute values of the injection voltage and the error current, and

a wireless communication unit configured to transmit said absolute values to a stationary calculating unit configured to monitor the resistance of the field winding to earth.

41. A machine as claimed in claim 40, wherein:

the excitation system is supplied from an exciter with rotating a stator side, the injection voltage is supplied from the rotating stator side of the exciter.

42. A machine as claimed in claim 41, further comprising:

a filter circuit arranged in said injection and measuring unit to filter away harmonics and to block direct voltages.

43. A machine as claimed in claim 40, further comprising:

a comparator arranged to compare said absolute value of the error current with predetermined limit value and trip an alarm if said absolute value different from said predetermined limit value by a predetermined amount.

44. A machine as claimed in claim 43, further comprising:

a scaling unit arranged prior to the comparator and configured to normalize and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator.

45. A machine as claimed in claim 40, further comprising:

measuring means for measuring and transmitting a voltage and current of the field winding to a unit for calculating the rotor temperature.

46. A machine as claimed in claim 45, wherein:

the unit for calculating the rotor temperature is stationary and in that said measured voltage and current values for the field winding can be transmitted to said calculating unit via the wireless communication unit.

47. A machine as claimed in claim 46, further comprising:

an alarm connected to the unit for calculating which is configured to trip the alarm when a temperature exceeds a predetermined limit value.

48. A machine as claimed in claim 40, further comprising:

a stationary voltage source arranged to supply electricity to the injection circuit via a ring transformer.

49. A machine as claimed in claim 40, wherein:

the injection circuit is supplied from a constant voltage source.

50. A method employed in a rotating electric machine having a rotating field circuit and configured to be directly connected to a distribution or transmission network, wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, comprising the steps of:

supplying an injection voltage to a measuring circuit that is closed by way of an impedance between a field winding of the rotating electric machine and earth;

measuring a resulting error current in the measuring circuit;

forming rectified absolute values of the injection voltage and the resulting error current;

transmitting the rectified absolute values to a calculating unit so as to monitor a resistance of the field winding to earth.

51. A method as claimed in claim 50, wherein:

said measuring step includes filtering away harmonics in the measuring circuit.

52. A method as claimed in 50, further comprising a step of:

comparing said absolute values of the error current with predetermined limit values and tripping an alarm when said comparing step provides a result that is greater than a predetermined level.

53. A method as claimed in claim 52, further comprising:

normalizing and compensating for variations in the injection voltage prior to the comparing step.

54. A method employed in a rotating electric machine having a rotating field circuit and configured to be directly connected to a distribution or transmission network, wherein an electric field winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, comprising the steps of:

measuring a voltage and a current in the electric field winding;

providing measurement results determined in said measuring step to a processor; and

calculating a rotor temperature from the measurement results.

55. A rotating electric machine having a rotating field circuit, and configured to be directly connected to a distribution or transmission network, comprising:

an electric winding having

an electric conductor,

a first semiconducting layer surrounding the conductor,

a solid insulating layer surrounding the first layer, and

a second semiconducting layer surrounding the insulating layer;

means for supplying an injection voltage by way of an impedance between a field winding of the rotating electric machine and earth;

means for measuring a resulting error current from the injection voltage as supplied by said means for supplying;

means for forming rectified absolute values of the injection voltage and the resulting error current; and

means for transmitting the rectified absolute values to a means for monitoring a resistance of the field winding to earth.--

IN THE ABSTRACT OF THE DISCLOSURE

After the last page, please insert the following Abstract of the Disclosure:

--ABSTRACT OF THE DISCLOSURE

A rotating electric machine of a type with rotating field circuit, intended for direct connection to a distribution or transmission network. At least one electric winding of the machine includes at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer. A detecting circuit is also arranged to detect earth faults in the rotating field circuit. Methods of monitoring the resistance of the field winding to earth and of determining the rotor temperature in such a machine is also described.--

REMARKS

Favorable consideration of this application as presently amended and in light of the following discussion is respectfully requested. Claims 28-55 are pending, Claims 1-27 having been cancelled without prejudice or disclaimer and Claims 28-55 having been added by way of the present amendment. New Claims 28-55 find support in original Claims 1-27 and thus add no new matter. An Abstract has been added, consistent with U.S. patent drafting procedure.

Because several amendments have been made to the specification, consistent with U.S. patent drafting practice, a substitute specification is filed herewith in addition to a marked-up copy of the original application. Please enter this substitute specification. To the extent any changes made by the substitute specification are deemed to be substantively inconsistent with the originally filed specification, these changes should be construed as typographical errors and the language included in the originally filed PCT specification should be construed as containing the controlling language.

The present document is one of a set of patent applications containing related technology as was discussed in "Response to Petition Under 37 C.F.R. §1.182 Seeking Special Treatment Relating to an Electronic Search Tool, and Decision on Petition Under 37 C.F.R. §1.183 Seeking Waiver of Requirements Under 37 C.F.R. §1.98", filed in the holding application (U.S. Patent Application No. 09/147,325). Consistent with this decision, a copy of the decision is filed herewith. Also, an Information Disclosure Statement is filed herewith including a 1449 form with references that are included as part of the specially created official digest in class 174. It is believed that submission of these materials and the reference

to the holding application (Serial No. 09/147,325) is sufficient for the present Examiner to consider the references in the holding application, consistent with the decision.

In view of the present amendment and in light of the foregoing comments, an examination on the merits is believed to be in order and an early and favorable action is respectfully requested.

Respectfully submitted,

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416 Rec'd PCT/PTO 28 MAR 2000

SUBSTITUTE SPECIFICATION

9847-0035-6X PCT
ENKEL 8294

TITLE OF THE INVENTION

ROTATING ELECTRIC MACHINE

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network. The invention also relates to the method of monitoring the resistance of the field winding to earth and of determining the rotor temperature.

Discussion of the Background:

The rotating electric machine according to the present invention may be e.g. a synchronous machine, dual-fed machine, asynchronous static current converter cascade, external pole machine or synchronous flow machine.

In order to connect machines of this type to distribution or transmission networks, in the followed called power networks, transformers have previously been used to step up the voltage to the level of the network, i.e. to the range of 130-400 kV.

Generators having a rated voltage of up to 36 kV are described by Paul R. Siedler in an article entitled "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932, pages 524-527. These generators include windings of high-voltage cable in which the insulation is divided into various layers having different dielectric constants. The insulating material used are made of various combinations of the three components mica-foil-mica, varnish and paper.

It has now been discovered that by manufacturing windings for the machine mentioned above out of an insulated high-voltage electric conductor with solid insulation of a type similar to cables for power transmission, the voltage of the machine can be increased to such levels that the machine can be connected directly to any power network without an intermediate transformer. A typical operating range for these machines is 30 to 800 kV.

Furthermore, in system solutions based on brushless exciters for excitation of a synchronous machine, for instance, the rotor winding of the synchronous machine is normally not monitored for earth faults.

An object of the present invention is to provide such a rotating electric machine for direct connection to power networks, with the ability to detect earth faults in the rotating field circuit.

SUMMARY OF THE INVENTION

This object is achieved with a rotating electric machine of the type described in the introductory portion with the characterizing features described herein.

The insulating conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XPLE-cables or cables with EPR-insulation. Such a cable has an inner conductor composed of one or more strands, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this inner semiconducting layer and an

outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the machine according to the invention is based primarily on winding systems in which the winding is formed from conductors which are bent during assembly. The flexibility of a XPLE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term "flexible" is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and relative of thermal expansion. In a XPLE-cable, for instance, the insulating layer is made of cross-linked, low-density polyethylene, and the semiconducting layers are made of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such

as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentane (PMP), cross-linked materials such as cross-linked polyethylene (XLPE or PEX), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylymp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be of the same order of magnitude. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damages appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially

equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but at the same time sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding with these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

According to advantageous embodiments of the machine in accordance with the invention an excitation system for supplying the field circuit has a part rotating with the field circuit, and parts of the detecting circuit for earth faults are arranged in the rotating part. The detecting circuit has a rotating injection circuit for application on a measuring circuit that is closed through the impedance between field winding and earth, an injection voltage and a measuring unit for measuring the error current resulting in the measuring circuit from the injection voltage, rectifier units being arranged to form rectified absolute values of the injection voltage and the error current, a wireless communication unit also being provided to transmit said absolute values to a stationary calculating unit for monitoring the resistance of the field winding to earth. This means that only two process signals, namely the rectified absolute values for the injection voltage and the error current, need be transmitted to the stationary part to determine the resistance value to earth. This results in a limited signal interface between the stationary and the rotating part, with less demand on the slip ring-free transmission. The number of rotating units for injection and measuring is also limited. The calculating unit suitably has a computer equipment for implementing requisite calculation

algorithms.

According to another advantageous embodiment of the machine in accordance with the invention, in which the excitation system is supplied from an exciter with rotating stator side, the injection circuit is supplied from the rotating stator side of the exciter. Voltage fluctuations can then be compensated for by way of software functions in the computer equipment. These functions are based on known circumstances relating to phase shifting in RC circuits and calculation of both real and imaginary current components and absolute values for limit value determination.

According to yet another advantageous embodiment of the machine in accordance with the invention filter circuits are arranged in the measuring circuit in order to filter away harmonics and to block direct voltages. The filter time constants for filtering harmonics shall in that case correspond to the period time of the injection voltage in order to enable the harmonics to be effectively filtered off.

According to yet another advantageous embodiment of the machine in accordance with the invention scaling units are arranged prior to a comparator for comparison of said absolute values of the error current with predetermined limit values, which scaling units are arranged to normalize and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator. This is of significance since the injection voltage is altered with the excitation.

According to another advantageous embodiment of the machine in accordance with the invention the above-mentioned problem is solved by the injection circuit being supplied from a constant voltage source.

According to yet another advantageous embodiment of the machine in 30 accordance with the invention a stationary voltage source is arranged to supply the injection circuit via a

ring transformer. This enables earth faults to be detected even when the rotor is stationary.

BRIEF DESCRIPTION OF THE DRAWINGS

To further explain the invention, embodiments of the invention selected by way of example will be described in more detail with reference to the accompanying drawings in which

Figure 1 shows a cross section through the insulated conductor used for windings in the machine according to the invention,

Figure 2 shows a diagram of the excitation system with circuit for detecting earth faults in the field circuit and with mechanism for determining the rotor temperature in an embodiment of the rotating electric machine according to the invention,

Figures 3-6 show equivalent circuits for the measuring circuit included in the detecting circuit for earth faults, in different error cases, and

Figure 7 illustrates an embodiment of a scaling unit for normalizing and compensating the measured signal.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Figure 1 shows a cross section through an insulated conductor 11 intended for use in at least one of the windings of the machine in accordance with the invention. The insulated conductor 11 thus has a number of strands 35 made of copper (Cu), for instance, and having circular cross section. These strands 35 are arranged in the middle of the insulated conductor 11. Around the strands 35 is a first semiconducting layer 13. Around the first semiconducting layer 13 is an insulating layer 37, e.g. XPLE insulation. Around the insulating layer 37 is a second semiconducting layer 15. The insulated conductor is flexible and this property is retained throughout its service life. The three layers 13, 37, 15 are such that they adhere to each other even when the insulated conductor is bent. The insulated conductor has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm^2.

Figure 2 shows a circuit diagram of the excitation system in a rotating 30 electric machine with one or more windings of the insulated conductor shown in Figure 1 to enable direct connection to a power network. The excitation system has both a rotating injection and supply circuit 16 and a stationary unit 20 for detecting earth faults and for calculating the rotor temperature.

The excitation system thus includes a rotating part 1 equipped with a rotating exciter G3 which, from the rotating stator side, supplies a diode or thyristor bridge 12 which is connected by its direct current side to the field winding 14 of the machine. An injection and measuring circuit 16 is also provided for use when detecting earth faults in the field circuit, and measuring mechanism 18 to determine the field voltage for temperature calculations. The rotating part 1 also includes a supply mechanism 5 to supply the electronic equipment of the rotating part, and also with a communication unit 3. A measuring mechanism 25 is also

provided for measuring the field current I_F. Wireless communication between the rotating part 1 and the stationary equipment 20 is achieved with the aid of the communication unit 3 and a stationary communication unit 4.

By way of an injection circuit having a transformer 8 for voltage adjustment and galvanic separation, the measuring circuit is supplied with a suitable voltage U via an injection transformer 9, said voltage thus being withdrawn from the AC side of the exciter G3. The measuring circuit includes two parallel RC branches and is closed through the impedance of the field winding 14 to earth. The RC branches serve as current limitation and DC insulation.

The current I generated in the measuring circuit by the injection voltage U is sensed by a sensing circuit 22 via a measuring transformer 11 and converted to a corresponding voltage signal which is filtered in the filter circuit 24 and rectified in the rectifier 26. The voltage signal U_I obtained on the output of the rectifier 26, thus represents the amplitude value for the fundamental tone of the current I in the measuring circuit.

The injection voltage U is also filtered and rectified in similar manner in the filter circuit 28 and the rectifier 30, a voltage signal U_U being obtained on the output of the rectifier, which represents the amplitude value for the fundamental tone of the injection voltage U.

The filter time constants T for the filters 24, 28 shall correspond to the period time of the injection voltage U and measured current I to effectively filter off all harmonics.

The voltage signals U_U, U_I are transmitted by the communication units 3, 4 to the stationary part 20 for calculation of the resistance of the field winding 14 to earth from these signals in the calculating unit 17.

The calculating unit 17 thus enables earth faults in the field winding 14 to be

monitored, and an alarm is tripped when the resistance of the field winding 14 to earth falls below a predetermined level.

R_j denotes the resistance of the field winding 14 to earth, i.e. in practice the resistance to the iron mass of the rotating part, and C_j denotes the capacitance of the winding 14 to earth. The resistance R_j may in principle vary from infinitely large to zero.

Figure 3 illustrates an equivalent circuit for the measuring circuit if $R_j = 0$, i.e. the "worst" case with the field winding 14 short-circuited to earth. The resultant current 11 in the circuit can be calculated using known values for the resistance R, capacitance C and injection voltage U, and suitable normalizing constants can be determined in accordance with principles described in conjunction with Figure 7 below. The absolute value of the current 11 corresponds to the value of the measured signal U1 that is transmitted to the calculating unit 17, as described above in conjunction with Figure 2.

The diagram to the right of the equivalent circuit in Figure 3 illustrates magnitudes and phase positions of the injection voltage U. composed of a resistive component U_r and a capacitive component U_c, and the current 11.

Figure 4 shows a corresponding equivalent circuit in fault-free state, i.e. the contact resistance to earth is $R_j = \infty$. The capacitance C_j of the winding 14 to earth can be determined using known values for the injection voltage U, resistance R and capacitance C and measuring the current I2.

As in Figure 3, the diagram to the right of the circuit shows magnitudes and phase positions of the injection voltage U, composed of a resistive component U_r in phase with the current I2, and a capacitive component consisting of the voltage drop U_c over the capacitors C and the voltage drop U_j over the capacitance C_j, and the current I2.

Figure 5 shows a corresponding equivalent circuit in the event of a contact resistance

between winding 14 and earth R_j, where $0<R_j<\infty$, i.e. a state between the states illustrated in Figures 3 and 4. Different limit values for the current 13 for alarm and tripping can, as mentioned in conjunction with Figure 2, be calculated using known values for the resistances R, capacitances C, earthing capacitance C_j, injection voltage U, and the currents I1 and I2 from the cases shown in Figures 3 and 4, as well as predetermined limit values for the contact resistance to earth R_j.

The impedance Z1 across the two parallel branches, each containing 2R in series with 2C, is thus

$$Z1 = R - J\frac{1}{wC}$$

and the transition impedance between the winding 14 and earth Z2

$$Z2 = \frac{R_j}{1+JwRjCj}$$

the current 13 being obtained from

13 = U/(Z1 + Z2)

The diagram to the right of the circuit in Figure 5 illustrates magnitudes 5 and phase positions of voltages and currents in a corresponding manner as in Figures 3 and 4. From this diagram, it is clear that the current 13 is in phase with the current 12 in Figure 4 and includes a current component I_{Cj} through the transition capacitance C_j and a current component I_{rj} through the contact resistance R_j, the latter two current components being at right angles to each other in the diagram, i.e. phase-shifted 90°.

Figures 3 and 5 shows cases with errors on the DC side of the supply to the field winding from the exciter G3, see Figure 2. Figure 6 illustrates a situation with faults on the

AC side of the rectifier bridge 12. A fault on the AC side is characterized by the addition of an extra supply source U_{ac}, and by the absolute value of the current being composed of two components - one driven by the ordinary injection voltage U and one driven by the potential level of the fault point to earth, represented by the voltage U_{ac}. In the event of faults on the AC side, therefore, the total absolute value of the error current will exceed the limit values calculated in the case illustrated in Figure 5 - often by a good margin - resulting in the alarm being tripped.

The corresponding phase diagram to the right in Figure 6 corresponds to that in Figure 5.

In the event of variations in the injection voltage U the measured signals must be compensated by scaling. Alternatively, the predetermined limit values for alarm tripping or releasing, etc. in a comparator must be changed, which is considerably more complicated.

Figure 7 shows a scaling unit 32, 34 included in the calculating unit 17 in Figure 2. In this scaling unit 32, 34 the measured value U_I, representing the absolute value of the current 1, is normalized by multiplying it by a normalizing constant K1. A suitable magnitude for the normalizing constant K1 can be determined by means of a measuring procedure in accordance with Figure 3.

Similarly, the measured signal U_U for variations in the injection voltage U is compensated by scaling with a compensation constant K2, wherein $K2=U_U$ at the time of normalizing the measured signal U_I. The current I_n, normalized and compensated with regard to variations in the injection voltage U, is supplied to a comparator 38 in which this current I_n is compared with various predetermined limit values Lim 1, Lim 2. Lim 3 for tripping the alarm, emitting a tripping signal, etc.

The measuring mechanism 18 measures the field voltage and the measuring unit 25

measures the field current, and corresponding measured signals U_F and I_F are transmitted via the wireless communication units 3, 4 to a unit 40 in the stationary equipment 20 for calculating the rotor temperature from these measured signals, see Figure 2. In the filter 42 in the measuring means 18 the field voltage signal is filtered with a time constant T1 which shall correspond to 0.3 times the no-load time constant of the field winding 14. When the electric machine is not synchronized on the network, it has a time constant corresponding to the no-load time constant, whereas if the machine is connected to the network this time constant is altered by a factor of approximately 0.3, depending on the inductance of the network.

The unit 40 may in turn be connected to an indicating mechanism for the rotor temperature or alarm, for instance, or tripping mechanism to activate these depending on the determined value for the rotor temperature.

Numerous modifications and variations of the embodiments described above are of course possible within the scope of the invention. The invention is thus also applicable to stationary solutions such as static exciters, and the supply voltage to the injection unit can be transformed to the rotating part by means of a ring transformer so that earth faults can also be detected when the machine is stationary.

CLAIMS

1. A rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, characterized in that at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, and in that a detecting circuit is provided for detecting earth faults in the rotating field circuit.

2. A machine as claimed in claim 1, characterized in that the potential of the first layer is substantially similar to the potential of the conductor.

3. A machine as claimed in claim 1 or claim 2, characterized in that the second layer is arranged to form a substantially equipotential surface surrounding the conductor.

4. A machine as claimed in claim 3, characterized in that the second layer is connected to a predetermined potential.

5. A machine as claimed in claim 4, characterized in that said predetermined potential is earth potential.

6. A machine as claimed in any of the preceding claims, characterized in that at least two adjacent layers of the machine winding have substantially the same coefficients of

thermal expansion.

7. A machine as claimed in any of the preceding claims, characterized in that the conductor comprises a number of strands, at least some of which are in electrical contact with each other.

8. A machine as claimed in any of the preceding claims, characterized in that each of said three layers is firmly joined to adjacent layers along substantially its whole contact surface.

9. A machine as claimed in any of the preceding claims, characterized in that said layers are arranged to adhere to each other even when the insulated conductor is bent.

10. A rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, characterized in that at least one winding of the machine is formed of a cable comprising one or more current carrying conductors, each conductor having a number of strands, an inner semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around said inner semiconducting layer, and an outer semiconducting layer arranged around the insulating layer, and in that a detecting circuit is arranged to detect earth faults in the rotating field circuit.

11. A machine as claimed in claim 10, characterized in that said cable comprises a sheath.

12. A machine as claimed in any of the preceding claims, characterized in that an excitation system for supplying the field circuit comprises a part rotating with the field circuit, and in that an injection and measuring unit for said detecting circuit is arranged in said rotating part.

13. A machine as claimed in any of the preceding claims, characterized in that the detecting circuit comprises an injection circuit for application on a measuring circuit that is closed through the impedance between field winding and earth, an injection voltage and a measuring unit for measuring the error current resulting in said measuring circuit from the injection voltage, and in that rectifier units are arranged to form rectified absolute values of the injection voltage and the error current, a wireless communication unit also being provided to transmit said absolute values to a stationary calculating unit for monitoring the resistance of the field winding to earth.

14. A machine as claimed in claim 13, wherein the excitation system is supplied from an exciter with rotating stator side, characterized in that the injection circuit is supplied from the rotating stator side of the exciter.

15. A machine as claimed in claim 13 or claim 14, characterized in that filter circuits are arranged in said measuring circuit in order to filter away harmonics and to block direct voltages.

16. A machine as claimed in any of claims 13-15, characterized in that a comparator is arranged to compare said absolute values of the error current with predetermined limit

values and, depending on the result of the comparison, to trip alarms.

17. A machine as claimed in claim 16, characterized in that scaling units are arranged prior to the comparator in order to normalize and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator.

18. A machine as claimed in any of the preceding claims, characterized in that measuring means are arranged to measure the voltage and current of the field winding and transmit these values to a unit for calculating the rotor temperature.

19. A machine as claimed in claim 18, characterized in that the unit for calculating the rotor temperature is stationary and in that said measured voltage and current values for the field winding can be transmitted to said calculating unit via the wireless communication unit.

20. A machine as claimed in claim 18 or claim 19, characterized in that an alarm is connected to the calculating unit which alarm is tripped when the temperature exceeds a predetermined limit value.

21. A machine as claimed in claim 13, characterized in that a stationary voltage source is arranged to supply the injection circuit via a ring transformer.

22. A machine as claimed in claim 13, characterized in that the injection circuit is supplied from a constant voltage source.

23. A method for a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, characterized in that an injection voltage is supplied to a measuring circuit that is closed through the impedance between field winding and earth, and the resulting error current in the measuring circuit is measured, whereupon rectified absolute values of the injection voltage and the error current are formed and transmitted to a calculating unit for monitoring the resistance of the field winding to earth.

24. A method as claimed in claim 23, characterized in that harmonics in the measuring circuit are filtered away.

25. A method as claimed in 23 or claim 24, characterized in that said absolute values of the error current are compared with predetermined limit values and an alarm is tripped depending on the result of the comparison.

26. A method as claimed in claim 25, characterized in that prior to the comparison, the error current measured is normalized and compensated for variations in the injecting voltage.

27. A method for a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network,

wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, characterized in that the voltage and current of the field winding are measured and the rotor temperature is calculated from these measured values.

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ROTATING ELECTRIC MACHINE

Technical field

The present invention relates to a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network. The invention also relates to the method of monitoring the resistance of the field winding to earth and of determining the rotor temperature.

Background art

The rotating electric machine according to the present invention may be e.g. a synchronous machine, dual-fed machine, asynchronous static current converter cascade, external pole machine or synchronous flow machine.

In order to connect machines of this type to distribution or transmission networks, in the followed called power networks, transformers have previously been used to step up the voltage to the level of the network, i.e. to the range of 130-400 kV.

Generators having a rated voltage of up to 36 kV are described by Paul R. Siedler in an article entitled "36 kV Generators Arise from Insulation Research", Electrical World, 15 October 1932, pages 524-527. These generators comprise windings of high-voltage cable in which the insulation is divided into various layers having different dielectric constants. The insulating material used consists of various combinations of the three components mica-foil-mica, varnish and paper.

It has now been discovered that by manufacturing windings for the machine mentioned in the introduction out of an insulated high-voltage electric conductor with solid insulation of a type similar to cables for power transmission, the voltage of the machine can be increased to such levels that the machine can be connected directly to any power network without an intermediate transformer. A typical operating range for these machines is 30 to 800 kV.

Furthermore, in system solutions based on brushless exciters for excitation of a synchronous machine, for instance, the rotor winding of the synchronous machine is normally not monitored for earth faults.

The object of the present invention is to provide such a rotating electric machine for direct connection to power networks, with the ability to detect earth faults in the rotating field circuit.

Summary of the invention

This object is achieved with a rotating electric machine of the type described in the introductory portion with the characterizing features defined in claim 1.

The insulating conductor or high-voltage cable used in the present invention is flexible and is of the type described in more detail in WO 97/45919 and WO 97/45847. The insulated conductor or cable is described further in WO 97/45918, WO 97/45930 and WO 97/45931.

Thus, in the device in accordance with the invention the windings are preferably of a type corresponding to cables having solid, extruded insulation, like those currently used for power distribution, such as XPLE-cables or cables with EPR-insulation. Such a cable comprises an inner conductor composed of one or more strands, an inner semiconducting layer surrounding the conductor, a solid insulating layer surrounding this inner semiconducting layer and an outer semiconducting layer surrounding the insulating layer. Such cables are flexible, which is an important property in this context since the technology for the machine according to the invention is based primarily on winding systems in which the winding is formed from conductors which are bent during assembly. The flexibility of a XPLE-cable normally corresponds to a radius of curvature of approximately 20 cm for a cable 30 mm in diameter, and a radius of curvature of approximately 65 cm for a cable 80 mm in diameter. In the present application the term “flexible” is used to indicate that the winding is flexible down to a radius of curvature in the order of four times the cable diameter, preferably eight to twelve times the cable diameter.

The winding should be constructed to retain its properties even when it is bent and when it is subjected to thermal or mechanical stress during operation. It is vital that the layers retain their adhesion to each other in this context. The material properties of the layers are decisive here, particularly their elasticity and

relative coefficients of thermal expansion. In a XPLE-cable, for instance, the insulating layer consists of cross-linked, low-density polyethylene, and the semiconducting layers consist of polyethylene with soot and metal particles mixed in. Changes in volume as a result of temperature fluctuations are completely absorbed as changes in radius of the cable and, thanks to the comparatively slight difference between the coefficients of thermal expansion in the layers in relation to the elasticity of these materials, the radial expansion can take place without the adhesion between the layers being lost.

The material combinations stated above should be considered only as examples. Other combinations fulfilling the conditions specified and also the condition of being semiconducting, i.e. having resistivity within the range of 10^{-1}-10^{6} ohm-cm, e.g. 1-500 ohm-cm, or 10-200 ohm-cm, naturally also fall within the scope of the invention.

The insulating layer may consist, for example, of a solid thermoplastic material such as low-density polyethylene (LDPE), high-density polyethylene (HDPE), polypropylene (PP), polybutylene (PB), polymethyl pentane (PMP), cross-linked materials such as cross-linked polyethylene (XLPE or PEX), or rubber such as ethylene propylene rubber (EPR) or silicon rubber.

The inner and outer semiconducting layers may be of the same basic material but with particles of conducting material such as soot or metal powder mixed in.

The mechanical properties of these materials, particularly their coefficients of thermal expansion, are affected relatively little by whether soot or metal powder is mixed in or not - at least in the proportions required to achieve the conductivity necessary according to the invention. The insulating layer and the semiconducting layers thus have substantially the same coefficients of thermal expansion.

Ethylene-vinyl-acetate copolymer/nitrile rubber, butylymp polyethylene, ethylene-acrylate-copolymers and ethylene-ethyl-acrylate copolymers may also constitute suitable polymers for the semiconducting layers.

Even when different types of material are used as base in the various layers, it is desirable for their coefficients of thermal expansion to be of the same

order of magnitude. This is the case with the combination of the materials listed above.

The materials listed above have relatively good elasticity, with an E-modulus of E<500 MPa, preferably <200 MPa. The elasticity is sufficient for any minor differences between the coefficients of thermal expansion for the materials in the layers to be absorbed in the radial direction of the elasticity so that no cracks or other damages appear and so that the layers are not released from each other. The material in the layers is elastic, and the adhesion between the layers is at least of the same magnitude as in the weakest of the materials.

The conductivity of the two semiconducting layers is sufficient to substantially equalize the potential along each layer. The conductivity of the outer semiconducting layer is sufficiently large to contain the electrical field in the cable, but at the same time sufficiently small not to give rise to significant losses due to currents induced in the longitudinal direction of the layer.

Thus, each of the two semiconducting layers essentially constitutes one equipotential surface, and the winding with these layers will substantially enclose the electrical field within it.

There is, of course, nothing to prevent one or more additional semiconducting layers being arranged in the insulating layer.

According to advantageous embodiments of the machine in accordance with the invention an excitation system for supplying the field circuit comprises a part rotating with the field circuit, and parts of the detecting circuit for earth faults are arranged in said rotating part. The detecting circuit comprises a rotating injection circuit for application on a measuring circuit that is closed through the impedance between field winding and earth, an injection voltage and a measuring unit for measuring the error current resulting in said measuring circuit from the injection voltage, rectifier units being arranged to form rectified absolute values of the injection voltage and the error current, a wireless communication unit also being provided to transmit said absolute values to a stationary calculating unit for monitoring the resistance of the field winding to earth. This means that only two process signals, namely the rectified absolute values for the injection voltage and the error current, need be transmitted to the stationary part to determine the

resistance value to earth. This results in a limited signal interface between the stationary and the rotating part, with less demand on the slip ring-free transmission. The number of rotating units for injection and measuring is also limited. The calculating unit suitably comprises a computer equipment for implementing requisite calculation algorithms.

According to another advantageous embodiment of the machine in accordance with the invention, in which the excitation system is supplied from an exciter with rotating stator side, the injection circuit is supplied from the rotating stator side of the exciter. Voltage fluctuations can then be compensated for by means of software functions in the computer equipment. These functions are based on known circumstances relating to phase shifting in RC circuits and calculation of both real and imaginary current components and absolute values for limit value determination.

According to yet another advantageous embodiment of the machine in accordance with the invention filter circuits are arranged in said measuring circuit in order to filter away harmonics and to block direct voltages. The filter time constants for filtering harmonics shall in that case correspond to the period time of the injection voltage in order to enable the harmonics to be effectively filtered off.

According to yet another advantageous embodiment of the machine in accordance with the invention scaling units are arranged prior to a comparator for comparison of said absolute values of the error current with predetermined limit values, which scaling units are arranged to normalise and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator. This is of significance since the injection voltage is altered with the excitation.

According to another advantageous embodiment of the machine in accordance with the invention the above-mentioned problem is solved by the injection circuit being supplied from a constant voltage source.

According to yet another advantageous embodiment of the machine in accordance with the invention a stationary voltage source is arranged to supply the injection circuit via a ring transformer. This enables earth faults to be detected even when the rotor is stationary.

Brief description of the drawings

To further explain the invention, embodiments of the invention selected by way of example will be described in more detail with reference to the accompanying drawings in which

Figure 1 shows a cross section through the insulated conductor used for windings in the machine according to the invention,

Figure 2 shows a diagram of the excitation system with circuit for detecting earth faults in the field circuit and with means for determining the rotor temperature in an embodiment of the rotating electric machine according to the invention,

Figures 3-6 show equivalent circuits for the measuring circuit included in the detecting circuit for earth faults, in different error cases, and

Figure 7 illustrates an embodiment of a scaling unit for normalising and compensating the measured signal.

Description of preferred embodiments of the invention

Figure 1 shows a cross section through an insulated conductor 11 intended for use in at least one of the windings of the machine in accordance with the invention. The insulated conductor 11 thus comprises a number of strands 35 made of copper (Cu), for instance, and having circular cross section. These strands 35 are arranged in the middle of the insulated conductor 11. Around the strands 35 is a first semiconducting layer 13. Around the first semiconducting layer 13 is an insulating layer 37, e.g. XPLE insulation. Around the insulating layer 37 is a second semiconducting layer 15. The insulated conductor is flexible and this property is retained throughout its service life. Said three layers 13, 37, 15 are such that they adhere to each other even when the insulated conductor is bent. The insulated conductor has a diameter within the interval 20-250 mm and a conducting area within the interval 80-3000 mm^2.

Figure 2 shows a circuit diagram of the excitation system in a rotating electric machine with one or more windings of the insulated conductor shown in Figure 1 to enable direct connection to a power network. The excitation system

comprises both a rotating injection and supply circuit 16 and a stationary unit 20 for detecting earth faults and for calculating the rotor temperature.

The excitation system thus comprises a rotating part 1 equipped with a rotating exciter G3 which, from the rotating stator side, supplies a diode or thyristor bridge 12 which is connected by its direct current side to the field winding 14 of the machine. An injection and measuring circuit 16 is also provided for use when detecting earth faults in the field circuit, and measuring means 18 to determine the field voltage for temperature calculations. The rotating part 1 also includes a supply means 5 to supply the electronic equipment of the rotating part, and also with a communication unit 3. A measuring means 25 is also provided for measuring the field current I_F. Wireless communication between the rotating part 1 and the stationary equipment 20 is achieved with the aid of the communication unit 3 and a stationary communication unit 4.

By means of an injection circuit comprising a transformer 8 for voltage adjustment and galvanic separation, the measuring circuit is supplied with a suitable voltage U via an injection transformer 9, said voltage thus being withdrawn from the AC side of the exciter G3. The measuring circuit includes two parallel RC branches and is closed through the impedance of the field winding 14 to earth. The RC branches serve as current limitation and DC insulation.

The current I generated in the measuring circuit by the injection voltage U is sensed by a sensing circuit 22 via a measuring transformer 11 and converted to a corresponding voltage signal which is filtered in the filter circuit 24 and rectified in the rectifier 26. The voltage signal U_I obtained on the output of the rectifier 26, thus represents the amplitude value for the fundamental tone of the current I in the measuring circuit.

The injection voltage U is also filtered and rectified in similar manner in the filter circuit 28 and the rectifier 30, a voltage signal U_U being obtained on the output of the rectifier, which represents the amplitude value for the fundamental tone of the injection voltage U.

The filter time constants T for the filters 24, 28 shall correspond to the period time of the injection voltage U and measured current I to effectively filter off all harmonics.

The voltage signals U_U, U_I are transmitted by the communication units 3, 4 to the stationary part 20 for calculation of the resistance of the field winding 14 to earth from these signals in the calculating unit 17.

The calculating unit 17 thus enables earth faults in the field winding 14 to be monitored, and an alarm is tripped when the resistance of the field winding 14 to earth falls below a predetermined level.

R_j denotes the resistance of the field winding 14 to earth, i.e. in practice the resistance to the iron mass of the rotating part, and C_j denotes the capacitance of the winding 14 to earth. The resistance R_j may in principle vary from infinitely large to zero.

Figure 3 illustrates an equivalent circuit for the measuring circuit if $R_j = 0$, i.e. the "worst" case with the field winding 14 short-circuited to earth. The resultant current I1 in the circuit can be calculated using known values for the resistance R, capacitance C and injection voltage U, and suitable normalising constants can be determined in accordance with principles described in conjunction with Figure 7 below. The absolute value of the current I1 corresponds to the value of the measured signal U1 that is transmitted to the calculating unit 17, as described above in conjunction with Figure 2.

The diagram to the right of the equivalent circuit in Figure 3 illustrates magnitudes and phase positions of the injection voltage U, composed of a resistive component U_r and a capacitive component U_C, and the current I1.

Figure 4 shows a corresponding equivalent circuit in fault-free state, i.e. the contact resistance to earth is $R_j = \infty$. The capacitance C_j of the winding 14 to earth can be determined using known values for the injection voltage U, resistance R and capacitance C and measuring the current I2.

As in Figure 3, the diagram to the right of the circuit shows magnitudes and phase positions of the injection voltage U, composed of a resistive component U_r in phase with the current I2, and a capacitive component consisting of the voltage drop U_C over the capacitors C and the voltage drop U_j over the capacitance C_j, and the current I2.

Figure 5 shows a corresponding equivalent circuit in the event of a contact resistance between winding 14 and earth R_j, where $0<R_j<\infty$, i.e. a state between the states illustrated in Figures 3 and 4. Different limit values for the current I3 for alarm and tripping can, as mentioned in conjunction with Figure 2, be calculated using known values for the resistances R, capacitances C, earthing capacitance C_j, injection voltage U, and the currents I1 and I2 from the cases shown in Figures 3 and 4, as well as predetermined limit values for the contact resistance to earth R_j.

The impedance Z1 across the two parallel branches, each containing 2R in series with 2C, is thus

$$Z1 = R - J \frac{1}{wC}$$

and the transition impedance between the winding 14 and earth Z2

$$Z2 = \frac{Rj}{1+JwRjCj}$$

the current I3 being obtained from

$$I3 = U/(Z1 + Z2)$$

The diagram to the right of the circuit in Figure 5 illustrates magnitudes and phase positions of voltages and currents in a corresponding manner as in Figures 3 and 4. From this diagram, it is clear that the current I3 is in phase with the current I2 in Figure 4 and includes a current component I_{Cj} through the transition capacitance Cj and a current component I_{rj} through the contact resistance R_j, the latter two current components being at right angles to each other in the diagram, i.e. phase-shifted 90^o.

Figures 3 and 5 shows cases with errors on the DC side of the supply to the field winding from the exciter G3, see Figure 2. Figure 6 illustrates a situation with faults on the AC side of the rectifier bridge 12. A fault on the AC side is characterized by the addition of an extra supply source U_{ac}, and by the absolute

value of the current being composed of two components - one driven by the ordinary injection voltage U and one driven by the potential level of the fault point to earth, represented by the voltage U_{AC}. In the event of faults on the AC side, therefore, the total absolute value of the error current will exceed the limit values calculated in the case illustrated in Figure 5 - often by a good margin - resulting in the alarm being tripped.

The corresponding phase diagram to the right in Figure 6 corresponds to that in Figure 5.

In the event of variations in the injection voltage U the measured signals must be compensated by scaling. Alternatively, the predetermined limit values for alarm tripping or releasing, etc. in a comparator must be changed, which is considerably more complicated.

Figure 7 shows a scaling unit 32, 34 included in the calculating unit 17 in Figure 2. In this scaling unit 32, 34 the measured value U_I, representing the absolute value of the current I, is normalised by multiplying it by a normalising constant K1. A suitable magnitude for the normalising constant K1 can be determined by means of a measuring procedure in accordance with Figure 3. Similarly, the measured signal U_U for variations in the injection voltage U is compensated by scaling with a compensation constant K2, wherein $K2=U_U$ at the time of normalising the measured signal U_I. The current I_n, normalised and compensated with regard to variations in the injection voltage U, is supplied to a comparator 38 in which this current I_n is compared with various predetermined limit values Lim 1, Lim 2, Lim 3 for tripping the alarm, emitting a tripping signal, etc.

The measuring means 18 measure the field voltage and the measuring means 25 measures the field current, and corresponding measured signals U_F and I_F are transmitted via the wireless communication units 3, 4 to a unit 40 in the stationary equipment 20 for calculating the rotor temperature from these measured signals, see Figure 2. In the filter 42 in the measuring means 18 the field voltage signal is filtered with a time constant T1 which shall correspond to 0.3 times the no-load time constant of the field winding 14. When the electric machine

is not synchronized on the network, it has a time constant corresponding to the no-load time constant, whereas if the machine is connected to the network this time constant is altered by a factor of approximately 0.3, depending on the inductance of the network.

The unit 40 may in turn be connected to indicating means for the rotor temperature or alarm, for instance, or tripping means to activate these depending on the determined value for the rotor temperature.

Numerous modifications and variations of the embodiments described above are of course possible within the scope of the invention. The invention is thus also applicable to stationary solutions such as static exciters, and the supply voltage to the injection unit can be transformed to the rotating part by means of a ring transformer so that earth faults can also be detected when the machine is stationary.

CLAIMS

1. A rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, **characterized** in that at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, and in that a detecting circuit is provided for detecting earth faults in the rotating field circuit.

2. A machine as claimed in claim 1, **characterized** in that the potential of the first layer is substantially similar to the potential of the conductor.

3. A machine as claimed in claim 1 or claim 2, **characterized** in that the second layer is arranged to form a substantially equipotential surface surrounding the conductor.

4. A machine as claimed in claim 3, **characterized** in that the second layer is connected to a predetermined potential.

5. A machine as claimed in claim 4, **characterized** in that said predetermined potential is earth potential.

6. A machine as claimed in any of the preceding claims, **characterized** in that at least two adjacent layers of the machine winding have substantially the same coefficients of thermal expansion.

7. A machine as claimed in any of the preceding claims, **characterized** in that the conductor comprises a number of strands, at least some of which are in electrical contact with each other.

8. A machine as claimed in any of the preceding claims, **characterized** in that each of said three layers is firmly joined to adjacent layers along substantially its whole contact surface.

9. A machine as claimed in any of the preceding claims, **characterized** in that said layers are arranged to adhere to each other even when the insulated conductor is bent.

10. A rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, **characterized** in that at least one winding of the machine is formed of a cable comprising one or more current carrying conductors, each conductor having a number of strands, an inner semiconducting layer arranged around each conductor, an insulating layer of solid insulating material arranged around said inner semiconducting layer, and an outer semiconducting layer arranged around the insulating layer, and in that a detecting circuit is arranged to detect earth faults in the rotating field circuit.

11. A machine as claimed in claim 10, **characterized** in that said cable comprises a sheath.

12. A machine as claimed in any of the preceding claims, **characterized** in that an excitation system for supplying the field circuit comprises a part rotating with the field circuit, and in that an injection and measuring unit for said detecting circuit is arranged in said rotating part.

13. A machine as claimed in any of the preceding claims, **characterized** in that the detecting circuit comprises an injection circuit for application on a measuring circuit that is closed through the impedance between field winding and earth, an injection voltage and a measuring unit for measuring the error current resulting in said measuring circuit from the injection voltage, and in that rectifier units are arranged to form rectified absolute values of the injection voltage and the

error current, a wireless communication unit also being provided to transmit said absolute values to a stationary calculating unit for monitoring the resistance of the field winding to earth.

14. A machine as claimed in claim 13, wherein the excitation system is supplied from an exciter with rotating stator side, **characterized** in that the injection circuit is supplied from the rotating stator side of the exciter.

15. A machine as claimed in claim 13 or claim 14, **characterized** in that filter circuits are arranged in said measuring circuit in order to filter away harmonics and to block direct voltages.

16. A machine as claimed in any of claims 13-15, **characterized** in that a comparator is arranged to compare said absolute values of the error current with predetermined limit values and, depending on the result of the comparison, to trip alarms.

17. A machine as claimed in claim 16, **characterized** in that scaling units are arranged prior to the comparator in order to normalise and compensate the measured error current for variations in the injection voltage before the error current is supplied to the comparator.

18. A machine as claimed in any of the preceding claims, **characterized** in that measuring means are arranged to measure the voltage and current of the field winding and transmit these values to a unit for calculating the rotor temperature.

19. A machine as claimed in claim 18, **characterized** in that the unit for calculating the rotor temperature is stationary and in that said measured voltage and current values for the field winding can be transmitted to said calculating unit via the wireless communication unit.

20. A machine as claimed in claim 18 or claim 19, **characterized** in that an alarm is connected to the calculating unit which alarm is tripped when the temperature exceeds a predetermined limit value.

21. A machine as claimed in claim 13, **characterized** in that a stationary voltage source is arranged to supply the injection circuit via a ring transformer.

22. A machine as claimed in claim 13, **characterized** in that the injection circuit is supplied from a constant voltage source.

23. A method for a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, **characterized** in that an injection voltage is supplied to a measuring circuit that is closed through the impedance between field winding and earth, and the resulting error current in the measuring circuit is measured, whereupon rectified absolute values of the injection voltage and the error current are formed and transmitted to a calculating unit for monitoring the resistance of the field winding to earth.

24. A method as claimed in claim 23, **characterized** in that harmonics in the measuring circuit are filtered away.

25. A method as claimed in 23 or claim 24, **characterized** in that said absolute values of the error current are compared with predetermined limit values and an alarm is tripped depending on the result of the comparison.

26. A method as claimed in claim 25, **characterized** in that prior to the comparison, the error current measured is normalised and compensated for variations in the injecting voltage.

27. A method for a rotating electric machine of a type with rotating field circuit, which machine is intended for direct connection to a distribution or transmission network, wherein at least one electric winding of the machine comprises at least one electric conductor, a first layer with semiconducting properties surrounding the conductor, a solid insulating layer surrounding the first layer, and a second layer with semiconducting properties surrounding the insulating layer, **characterized** in that the voltage and current of the field winding are measured and the rotor temperature is calculated from these measured values.

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Fig. 2

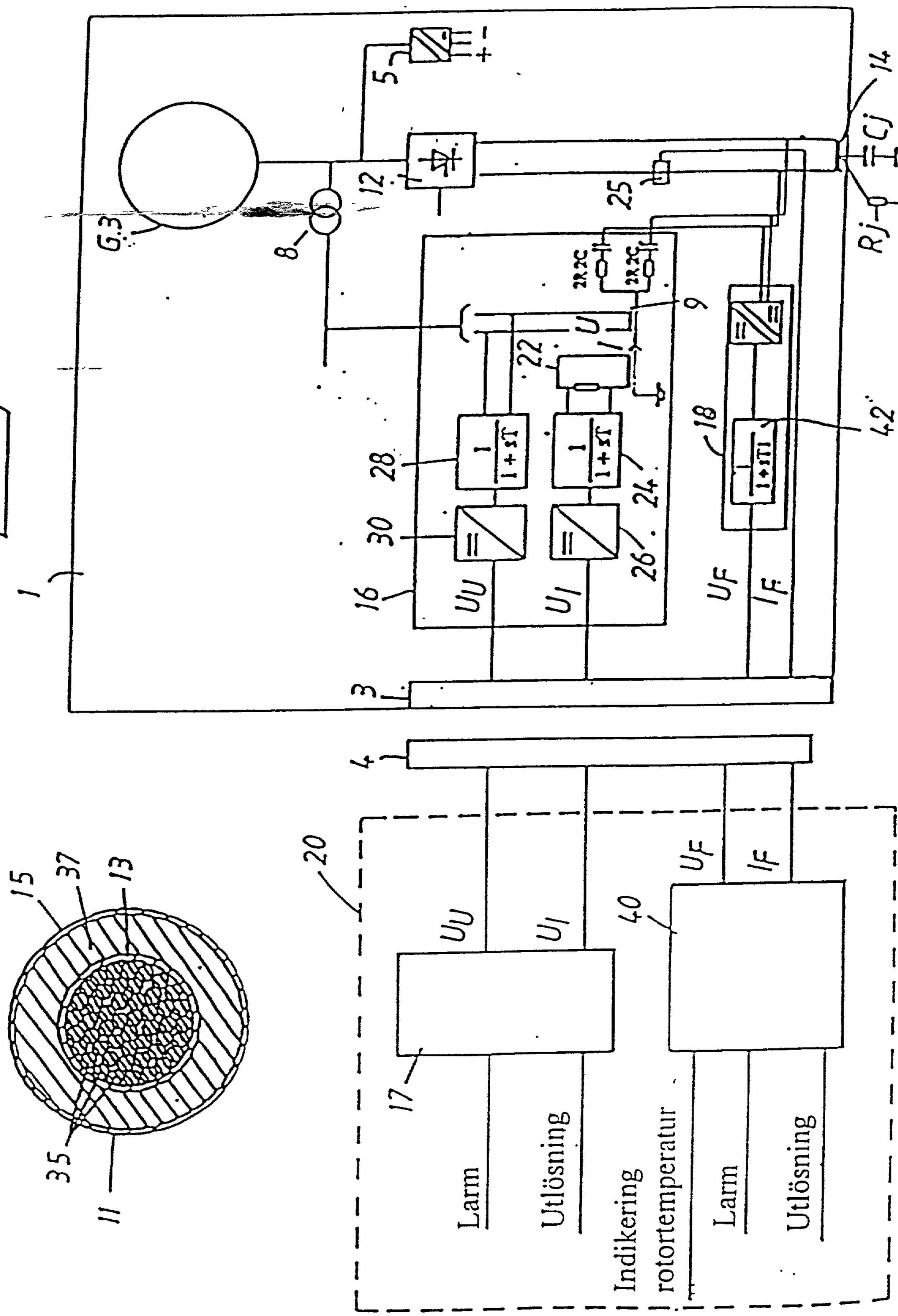


Fig. 1

Fig. 3

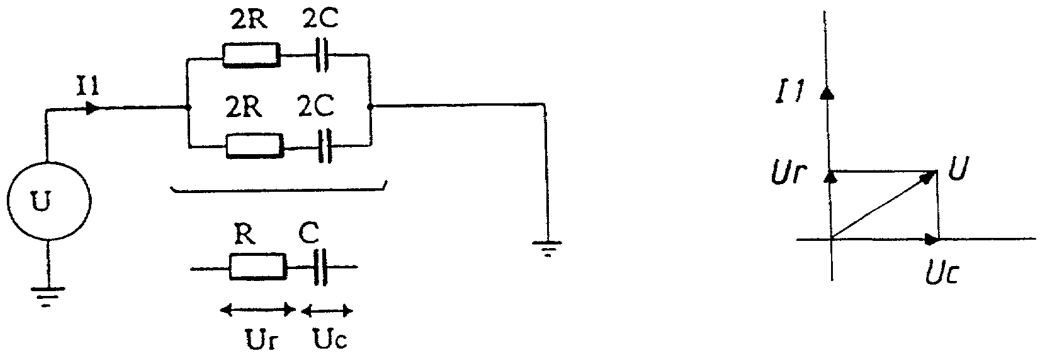


Fig. 4

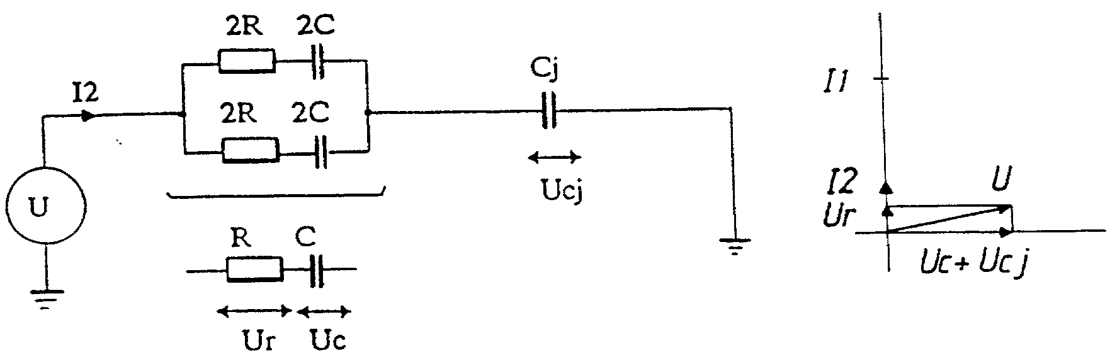


Fig. 5

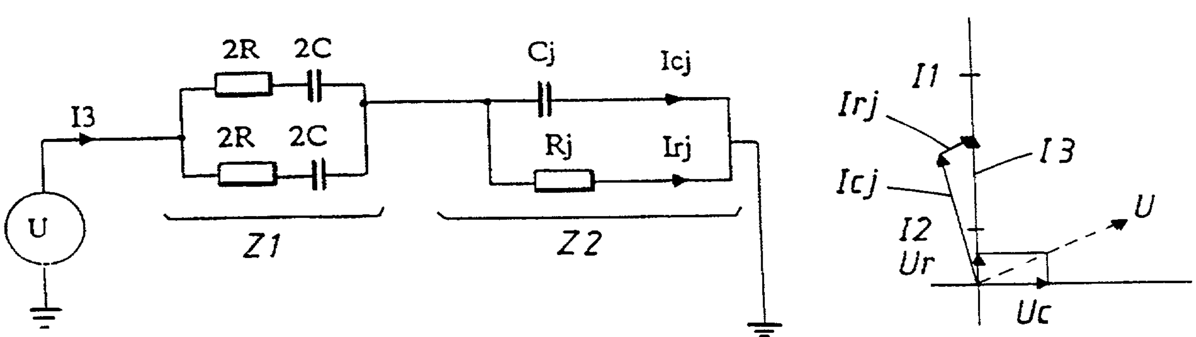
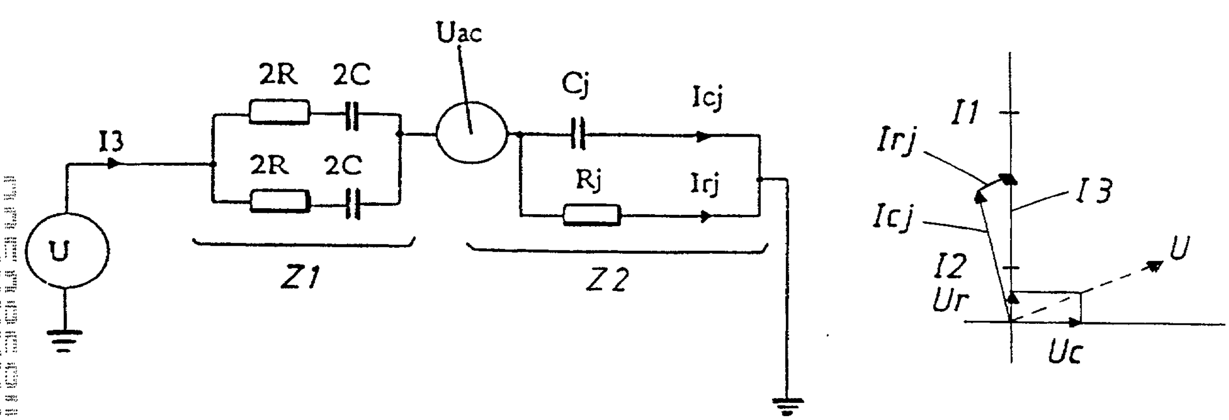


Fig. 6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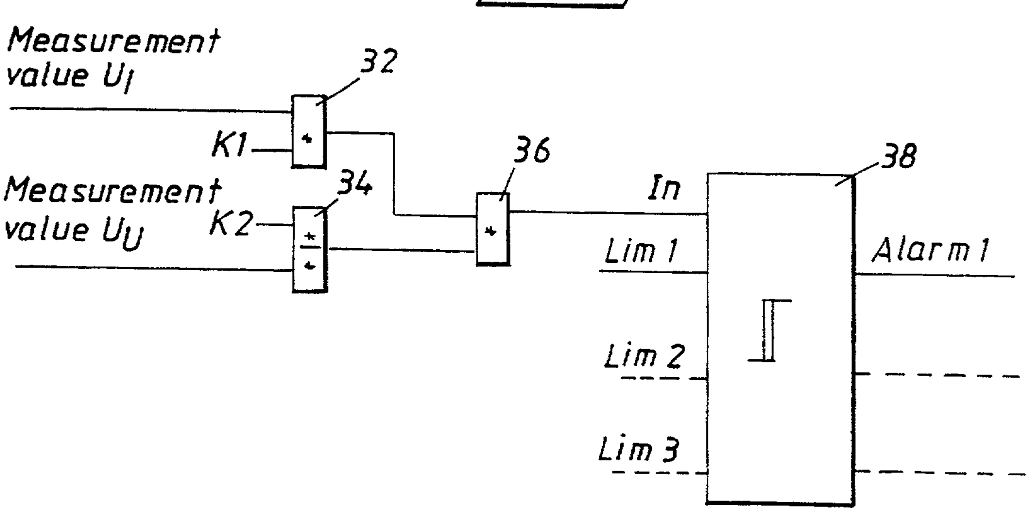
Ur
U
Uc

Fig. 7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K2
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Lim 1
Alarm 1
Lim 2
Lim 3

Declaration, Power Of Attorney and Petition

WE (I) the undersigned inventor(s), hereby declare(s) that:

My residence, post office address and citizenship are as stated below next to my name,

We (I) believe that we are (I am) the original, first, and joint (sole) inventor(s) of the subject matter which is claimed and for which a patent is sought on the invention entitled

ROTATING ELECTRIC MACHINE

the specification of which

☐ is attached hereto.

☒ was filed on 28 March 2000 as

Application Serial No. 09/508,684

and amended on ______.

☒ was filed as PCT international application

Number PCT/SE98/01740

on 29 September 1998,

and was amended under PCT Article 19

on ______ (if applicable).

We (I) hereby state that we (I) have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

We (I) acknowledge the duty to disclose information known to be material to the patentability of this application as defined in Section 1.56 of Title 37 Code of Federal Regulations.

We (I) hereby claim foreign priority benefits under 35 U.S.C. § 119(a)-(d) or § 365(b) of any foreign application(s) for patent or inventor's certificate, or § 365(a) of any PCT International application which designated at least one country other than the United States, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or PCT International application having a filing date before that of the application on which priority is claimed. Prior Foreign Application(s)

Application No.	Country	Day/Month/Year	Priority Claimed	
9703554-7	SWEDEN	30 September 1997	☒ Yes	☐ No
			☐ Yes	☐ No
			☐ Yes	☐ No
			☐ Yes	☐ No

We (I) hereby claim the benefit under Title 35, United States Code, § 119(e) of any United States provisional application(s) listed below.

(Application Number) (Filing Date)

(Application Number) (Filing Date)

We (I) hereby claim the benefit under 35 U.S.C. § 120 of any United States application(s), or § 365(c) of any PCT International application designating the United States, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States or PCT International application in the manner provided by the first paragraph of 35 U.S.C. § 112, I acknowledge the duty to disclose information which is material to patentability as defined in 37 CFR § 1.56 which became available between the filing date of the prior application and the national or PCT International filing date of this application.

Application Serial No.	Filing Date	Status (pending, patented, abandoned)
PCT/SE98/01740	29 September 1998	

And we (I) hereby appoint: Norman F. Oblon, Reg. No. 24,618; Marvin J. Spivak, Reg. No. 24,913; C. Irvin McClelland, Reg. No. 21,124; Gregory J. Maier, Reg. No. 25,599; Arthur I. Neustadt, Reg. No. 24,854; Richard D. Kelly, Reg. No. 27,757; James D. Hamilton, Reg. No. 28,421; Eckhard H. Kuesters, Reg. No. 28,870; Robert T. Pous, Reg. No. 29,099; Charles L. Gholz, Reg. No. 26,395; Vincent J. Sunderdick, Reg. No. 29,004; William E. Beaumont, Reg. No. 30,996; Robert F. Gnuse, Reg. No. 27,295; Jean-Paul Lavalleye, Reg. No. 31,451; Stephen G. Baxter, Reg. No. 32,884; Robert W. Hahl, Reg. No. 33,893; Richard L. Treanor, Reg. No. 36,379; Steven P. Weihrouch, Reg. No. 32,829; John T. Goolkasian, Reg. No. 26,142; Richard L. Chinn, Reg. No. 34,305; Steven E. Lipman, Reg. No. 30,011; Carl E. Schlier, Reg. No. 34,426; James J. Kulbaski, Reg. No. 34,648; Richard A. Neifeld, Reg. No. 35,299; J. Derek Mason, Reg. No. 35,270; Surinder Sachar, Reg. No. 34,423; Christina M. Gadiano, Reg. No. 37,628; Jeffrey B. McIntyre, Reg. No. 36,867; Paul E. Rauch, Reg. No. 38,591; William T. Enos, Reg. No. 33,128; and Michael E. McCabe, Jr., Reg. No. 37,182; our (my) attorneys, with full powers of substitution and revocation, to prosecute this application and to transact all business in the Patent Office connected therewith; and we (I) hereby request that all correspondence regarding this application be sent to the firm of OBLON, SPIVAK, McCLELLAND, MAIER & NEUSTADT, P.C., whose Post Office Address is: Fourth Floor, 1755 Jefferson Davis Highway, Arlington, Virginia 22202.

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We (I) declare that all statements made herein of our (my) own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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1-00

Erland Sorensen
Signature of Inventor

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19 May 2000
Date

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Residence:

Signature of Inventor

Citizen of:

Post Office Address:

Date